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"Post-fire Successional Pathways in Engelmann Spruce-Subalpine Fir Forests in Central Idaho"
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MONITORING INITIAL PLANT SUCCESSION FOLLOWING LARGE FIRES IN SUBALPINE SPRUCE-FIR FORESTS IN CENTRAL IDAHO

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ABSTRACT

The importance of large fire events in shaping the structure and composition of Rocky Mountain subalpine forests has recently been emphasized. Subalpine forests dominated by Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) comprise a major proportion of wilderness and roadless areas managed with prescribed natural fire in the western United State, yet relatively little is known about the ecology of large fires. In 1994 a series of large fires burned several thousand hectares of spruce-fir forests in central Idaho. The purpose of this research was to obtain baseline data on initial postfire seedling establishment patterns, to develop a set of long-term projections based on initial postfire variability, and to use remote sensing to classify landscape level fire intensity and vegetation patterns for long-term monitoring. Permanent plots were established in high-severity (complete duff consumption), low-severity (duff layer intact) and unburned areas and first year seed fall and seedling establishment was sampled. The basal area development of each species was projected based on initial seedling densities and a conceptual successional model was developed to provide a reference point for long-term monitoring. Landsat Thematic Mapper (TM) satellite imagery was used to classify landscape level vegetation and fire behavior characteristics at 30 meter resolution and a Geographic Information System was used to incorporate this data into a relational database. First year seedling established differed significantly between high severity and low severity burns and was also strongly correlated with seed fall. The successional projections showed a wide range of possible values for lodgepole pine, Engelmann spruce, and subalpine fir, suggesting that post-fire succession can be a highly variable process in these forests. The TM imagery lacked the resolution to successfully classify fire severity or all of the successional communities in the model, but was useful for interpreting fire intensity and obtaining baseline data to monitor broad-scale vegetation patterns. Long term monitoring of the Corral Blackwell Fire will help us to better understand the post-fire dynamics of spruce-fir forests.

Key Words: Fire, subalpine forest, initial succession , remote sensing, seedling establishment.

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INTRODUCTION

A major landscape component in the Rocky Mountains is composed of subalpine forests dominated by Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) (Green and Van Hooser 1983). Fire has historically been one of the most important large-scale disturbances responsible for the initiation of new stands (Peet 1988). Mean fire return intervals vary between 150 and 400 years but are probably not cyclical (Arno 1980, Crane and Fischer 1986, Peet 1988, Romme and Knight 1981, Turner and Romme 1994). During periods of severe weather (Bessie and Johnson 1995, Nash and Johnson 1996) fires may become very large and burn with highly variable spatial patterns across the landscape (Turner and Romme 1994, Turner et al. 1994). Although smaller fires are more frequent, it is these large, weather-driven fire events that account for most of the area burned and are therefore considered to be most important in shaping the overall structure and composition of landscape (Bessie and Johnson 1995, Turner and Romme 1994, Agee 1993, Johnson and Wowchuk 1992).

Relatively little is known about the ecology of large fires in spruce-fir forests, especially regarding initial postfire environments and broad-scale successional patterns. In addition, long-term data on postfire stand development is generally lacking (Rebertus et al. 1992). This poses a major challenge to resource managers responsible for assessing the consequences of large fires in wilderness and roadless areas managed with prescribed natural fire. Several factors have contributed to this knowledge gap: large fires are infrequent, spruce-fir forests typically occur in remote and rugged terrain, complex spatial patterns produced by large fires (Turner et al. 1994)

are difficult to study from the ground, and postfire succession in harsh subalpine environments can be slow and involve multiple successional outcomes (Habeck and Mutch 1973). As a result, postfire monitoring covering large areas is rare and fire management plans are non-existent or vague.

Effective postfire monitoring at multiple spatial and temporal scales is important to accurately assess the effectiveness of any fire management plan and to improve our understanding of long-term dynamics in spruce-fir forests. Remote sensing and Geographic Information Systems (GIS) are tools that may help overcome some of the above mentioned barriers and aid in gathering baseline data for long-term monitoring. Remote sensing provides an efficient and economic method of analyzing and storing spatial data for very large areas. However, the spatial resolution of the satellite sensors impose limitations on the scale of the ecological patterns examined. Stand level data, which may be necessary to understand fine scale successional mechanisms, should be linked with landscape level data to provide better insight into spruce-fir dynamics following large fires.

Large fires in 1994 burned several thousand hectares of spruce-fir forests in a remote region of central Idaho. These fires provided a valuable opportunity to study initial postfire environments and to initiate long-term landscape monitoring, but much of the burn was in roadless or unmanaged areas which lacked adequate baseline data. The purpose of this study was to assess the importance of fire severity on initial postfire succession, to address questions regarding the relative importance of early postfire environments on long-term dynamics, and to

use remote sensing to map landscape level vegetation and fire patterns that can be used for long-term monitoring. The objectives of this paper were to 1) quantify initial seed fall and seedling establishment patterns in different levels of fire severity, 2) develop a set of baseline predictions of long-term succession based on initial variability that can be tested over time, and 3) use remotely sensed data to obtain baseline data and develop a data base for long-term postfire monitoring. This first year results are presented here.

METHODS

Study Area

The Corral-Blackwell Complex Fire was ignited by lightning on August 3, 1994, on the Payette National Forest in central Idaho. The fire burned approximately 83,200 hectares before it was extinguished by precipitation on October 6, 1994. Elevations ranged from 600 meters to 2,735 meters, but more than 85% of the burned area was between 1,800 meters and 2,300 meters in mixed subalpine forests. Lodgepole pine (*Pinus contorta* Doug. Ex Loud. Var *latifolia*) is the most common associate in the spruce-fir zone and forms extensive mixed species forests with spruce and fir in the study area (Steele et al. 1981). Soils are generally characterized by moderate to well drained sandy loams of granitic origin (Steele et al. 1981).

Fire Severity and Initial Seedling Establishment

Fire Severity

Fire *severity* is defined here as the downward penetration of heat into the soil and is

expressed indirectly by the amount of littler and duff consumed (Schimmel and Granström 1996, Rowe 1983). It is distinguished from fire *intensity* which is the heat released upward into the canopy from a flaming front (commonly expressed indirectly by the amount of foliage consumption). Two discrete levels of fire severity were identified for this study: 1) *high-severity* burns are areas where 100% of the litter, duff, and humus were consumed and 2) *low-severity* burns are areas where the surface litter was burned but the duff and humus layer remained intact.

Plot Selection

Sixteen permanent 30 x 30 meter plots were randomly established in the burn in 1994 and georeferenced using a global positioning system. Four plots were established in high-severity burns, four in low-severity burns, and eight in unburned forests. All burned plots were established where crown fires completely consumed *all* foliage. The overstory composition consisted exclusively of Engelmann spruce, subalpine fir, and lodgepole pine (minimum 20% basal area of each species) and each plot was located on similar aspects (250° to 290°), elevations (within 140 meters), and slopes (<30% on mid-slope positions).

Seed Fall and Seedling Establishment

Seed fall was sampled by placing eight to ten metal seed traps (1 x 1 meters) in each plot immediately after the fire and recording the number and species of captured seeds in the Spring (tests for viability were not conducted). Seedling establishment was sampled at the end of

October using a series of systematic belt transects so that 100% of each plot was surveyed. Seed fall and seedling establishment between different burn severities was compared using the Kruskal Wallis test (Kruskal and Wallis 1952) and a nonparametric Tukey-type multiple comparison described in Zar (1990). A Spearman rank correlation procedure (Spearman 1904) was used to determine the correlation between seed fall and first year seedling establishment and the Student's *t*-test was used to test whether the coefficients were significantly greater than zero (Zar 1990).

Long-term successional projection

Initial variability in postfire seedling establishment between plots was used to establish a set of baseline predictions of potential long-term successional variability. The fire succession model FIRESUM (Keane et al. 1989) was utilized to project the basal area development of each species. The model was calibrated using local stand inventory plots and diameter and growth developed from the study area. The same growth, site, and mortality parameters were used so that differences between stand would represent only the different starting points of the plots.

Conceptual Successional Model

Due to the lack of information regarding postfire succession in the study area, we first developed a conceptual model that could be assessed over time with long-term monitoring. The model was based on a review of the literature, field observations of burned and unburned forests in study area, examination of stand inventory data from the study area, and input from field

personnel. Fire severity was selected as the primary determinant of postfire succession because most fires in spruce-fir forests are stand lethal regardless of the overstory intensity (Crane and Fisher 1986).

Classification of Postfire Vegetation Characteristics

Landsat Thematic Mapper (TM) satellite imagery was used to classify the prefire and initial postfire vegetation characteristics of the entire burn. The TM imagery has a spatial resolution of thirty meters and a spectral resolution of seven bands (Lillesand and Kiefer 1994). Two TM images encompassing the Corral-Blackwell fire were acquired: a pre-fire image taken on September 23, 1993, and a postfire image taken October 7, 1994 (one day after the last period of active fire spread). The classification was conducted as part of the Payette National Forest Integrated Resource Inventory Program (Boudreau and Maus 1996).

An unsupervised classification approach (Jensen 1996) was used to classify fire intensity using the ISODATA clustering routine in ERDAS IMAGINE (v. 8.2) image processing software. Eighty-two spectral clusters were identified and subsequently coded into four intensity classes: 1- high-intensity (complete crown consumption), 2- moderate-intensity (scorched needles remaining on 50-100% of the of the tree crowns or shrub), 3- low-intensity (only occasional scorched trees), and 4- unburned (see Wirth et al. 1996 for more detail). A supervised classification approach (Jensen 1996) was used to classify pre-fire species composition and land cover (including density) from the pre-fire TM image. Spectral characteristics used to delineate

each class were obtained from more than 200 photo interpreted training polygons randomly distributed throughout the study area. Three subalpine forest composition classes were delineated: 1) lodgepole pine (>90% cover), 2) high elevation conifer (any combination of Engelmann spruce, subalpine fir, and lodgepole pine), and high elevation conifer with whitebark pine. Coniferous forest density was classified into 1) open conifer (0-33% crown closure), 2) medium conifer (34-66% crown closure), and 3) dense conifer (67-100% crown closure).

Classification accuracy was assessed using an error matrix (Jensen 1996) to compare the classified data to reference data collected from the field. Field plots were established using a stratified random sampling approach, with the number of plots in each class ranging from seventeen to sixty-five. Two types of accuracy are calculated from the error matrix: 1) producer's accuracy, which is probability that a known class on the ground is classified correctly on the map, and 2) user's accuracy, which is the probability that an area on the map correctly depicts the corresponding area on the ground (Jensen 1996).

Postfire Database

A relational GIS database was created in ARC/INFO v7.1 (ESRI 1996) to link all remotely sensed data layers with digital elevation models (DEM) and existing GIS data from the study area (including daily fire perimeters and vegetation inventory data). A 7.5 USGS Digital Elevation Model was used to stratify areas with the same topographic and vegetative characteristics of the study plots so field data could be extrapolated to these areas.

RESULTS

Seed Fall and Seedling Establishment

Lodgepole pine accounted for the majority of first year seed fall in the burn, but differences between burned and unburned plots were not significant (alpha = 0.05). Lodgepole pine is primarily nonserotinous in the study area (Steele et al. 1981, Lotan 1975) and first year seed fall and was relatively low compared to some other burned areas (Anderson and Romme 1991, Lotan and Critchfield 1990, Lyon 1976). Spruce and fir seed fall also did not differ significantly between burned and unburned plots, although there was considerable variability between plots. There were significant differences in seedling establishment between the different levels of fire severity (alpha = 0.05). Lodgepole pine seedling establishment was highest in high severity burns and lowest in unburned plots, whereas subalpine fir seedling establishment was highest in low severity burns and lowest in the high severity burns. Egelmann spruce establishment did not differ between substrates.

There was a positive association between the number of seeds and the number of first year seedlings in the burn a year after the fire. Correlation coefficients for each species in the low-severity and high-severity plots ranged from 0.92 to 0.988 ($p < 0.05$) for all species in the burned plots, except for subalpine fir in the high-severity plots (0.19) where seedling establishment was absent regardless of seed fall. In contrast, all three species exhibited a weak correlation between seed fall and seedling establishment in the unburned plots, with subalpine fir

having the highest coefficient of 0.315 ($p > 0.05$).

Simulation of Successional Variability

The basal area projections based on the first year tree and seedling data revealed a wide range of values for each species (Figure 1). Projected basal area for lodgepole pine ranged from 2 to 15 meters^2/hectare at 50 years and from less than 5 to almost 20 meters^2/hectare at 100 years. Values for spruce ranged from 2 to 12 meters^2/hectare at 100 years and from 4 to 15 meters^2/hectare at 200 years. Because all variables except initial seedling density were held constant, differences in projected basal area are assumed to be primarily the result of differences in fire severity.

Conceptual Model

The conceptual successional model presented in Figure 2 is a modification of multiple pathway models developed for subalpine forests in Utah (Schimpf et al. 1980), Colorado (Stahelin 1943) and Wyoming (Anderson 1994). Key elements of the model are that fire severity directs the range of potential postfire successional pathways, each successional pathway can occur on any *single* site over time (rather than just the entire range of spruce-fir forests in the area), and once a successional pathway is initiated it does not necessarily develop unidirectionally toward a fir-spruce "climax" in the absence of fire.

Satellite Imagery Analysis

The TM imagery was very useful for mapping broad-scale fire and vegetation patterns. Approximately 26% of the area within the fire perimeter was classified as unburned. Of the burned area, 40% was classified as high-intensity, 30% as moderate-intensity, and 30% as low-intensity. The high-intensity burn class had the highest accuracy, yielding a producer's accuracy of 86% and a user's accuracy of 81%. These are very good results for an unsupervised classification. The low and moderate-intensity classes were more difficult to differentiate immediately after the fire. The producer's and user's accuracy of the low-intensity and moderate-intensity classes were below 65%. When the two classes are combined into one moderate/low-intensity class the user's accuracy increases to 77% and the overall accuracy of the fire intensity classification is 70% (Wirth et al. 1996). Unburned pixels within the fire had a producer's accuracy of 68% and a user's accuracy of 65%.

Successional communities in the conceptual model that corresponded to classes delineated in the satellite image classes included low shrub/herbaceous (dry brush and wet brush), herbaceous dominated (dry grass and wet grass), lodgepole pine, and mixed spruce-fir-lodgepole (high elevation conifer). Approximately 48% of the prefire vegetation was classified as high elevation conifer (mixed subalpine), 32% as lodgepole pine, and 8% consisted of meadow or shrub communities within subalpine forest zone. The accuracy varied widely between vegetation classes but was very high for the subalpine classes. The lodgepole pine class had a producer's accuracy of 74% and a user's accuracy of 70 %. The accuracy of the high elevation conifer class was slightly higher, having a producer's and user's accuracy 80%. This

class was widespread in the study area and was clearly distinguished from the lodgepole pine type. Approximately 60% of the prefire forest area was dense, 28% was medium, and 12% were open, although the error matrix indicated that the high density class was slightly overestimated.

DISCUSSION

Studies that have characterized postfire succession in spruce-fir forests have stressed single, deterministic successional patterns (Stromberg and Duncan 1991, Johnson and Fryer 1989, Aplet et al. 1988, Day 1972, Oosting and Reed 1956, Horton 1955, Cormack 1953, Bloomberg 1950), or have attributed variability primarily to differences in site quality and topographic position (Hansen 1940, Whipple and Dix 1979, Peet 1981, Romme and Knight 1981, Veblen 1986). Less attention has been focused on potential within site variability over time (&***Allen?). First year tree establishment data and basal area projections in different levels of fire severity show a wide range of variability for each species among the burned and unburned plots, suggesting that postfire succession in these subalpine environments can be highly variable. This pattern is consistent with the findings of Jull (1992), who found highly variable patterns of postfire seedling establishment in young spruce-fir forests in British Columbia, and Huff and Agee (1991) who concluded that postfire succession in subalpine forests in the Cascades was a variable and individualistic process that did not conform to generalized stand models.

Because the successional projections are based only on first year data, they are not intended as predictions of future communities, but rather to provide a framework for visualizing

the possible range of development of our plots based on the initial variability. Seedling survival is generally low in harsh subalpine environments (Alexander 1983, Fiedler et al. 1985). In addition, other disturbances such as wind and insects are critical during the long period between fires. Using projection models with various mortality routines can provide us with an idea of how important the initial postfire differences between plots will be in the future, which would otherwise be difficult to interpret. The relative importance of these initial differences over time can only be determined with long-term monitoring. Additional projections that include variable postfire climate, mortality, insect and disease scenarios, and other successional parameters such as trees/ha are currently being developed, and could help us to better understand some of these questions in the mean time.

Continued monitoring of seed fall and seedling establishment in the study plots will be valuable to determine the relative importance of the initial floristic composition and subsequent relay floristics on the long-term development of these stands. For example, the preliminary seed fall estimates for the second postfire year indicate that two of the burned plots received virtually no seed in 1995, although it was a bumper seed year for spruce and fir in the study area. This suggests that the first year seeds came primarily from seed in cones that "survived" the fire, and it is likely that these sites will not receive anymore seed for at least 25 years until the first-year seedlings can produce seed (or even longer if extensive mortality eliminates all of the first year seedlings). Depending on the seed availability, it is not uncommon for postfire tree regeneration to last 70 years or more in harsh subalpine environments, indefinitely prolonging a highly

variable period of stand development (Agee and Smith 1984, Habeck and Mutch 1973, Little and Peterson 1993). In some cases, initial colonizers start to die of old age before regeneration is complete (Huff and Agee 1991, Johnson and Fryer 1989). The second year data also shows that the number of spruce and fir seeds collected considerably higher in most plots, while lodgepole pine decreased slightly.

The satellite imagery analysis shows that remotely sensed data can serve as an effective and efficient source of pre-fire and postfire vegetation data where inventories are lacking or incomplete, and can provide valuable baseline information to monitor broad scale ecological patterns. The TM imagery proved to be very useful for classifying and analyzing the complex spatial mosaic of fire intensity patterns. This data can be used to study patch dynamics and applied toward a number of management applications. The development of relational GIS databases to link this baseline data with digital elevation models and other sources of available data (such as daily burn perimeters) provides a powerful tool for managers to monitor postfire successional patterns at the stand and landscape level. In addition, these landscape level data bases can be used to model large scale ecological processes and test existing models. Such basic baseline information following such a large fire in rugged terrain represents a significant contribution of remote sensing, and would probably not have been acquired otherwise.

The TM imagery lacked the resolution to detect finer scale patterns observed in the burn such as fire severity. Overall the variability in fire severity on the ground was too fine grained to be detected with the 30 meter resolution of the TM imagery. More importantly, a far greater area than expected burned with a high fire severity but only low to moderate fire intensity, making it

impossible to accurately analyze the surface characteristics through the canopy (both live and scorched). An initial assessment of the intensity and severity data from the field plots revealed a very poor relationship between fire intensity and severity within the burn, so modeling associations between intensity and severity was not attempted. It appears that in general, fire intensity may be a poor predictor of fire severity within the burn, especially within the high-intensity patches. In addition, we could not accurately classify many of the vegetation classes in the conceptual model could not be delineated with 30 meter TM data.

The Landsat TM imagery also lacked the spatial resolution to discriminate between all successional communities in the model. The use of more traditional stand based methodologies are probably required to test the proposed conceptual model. However, a scaled down version of the model was produced to match the resolution of the classified TM imagery (Figure 3). This level of detail can still provide useful landscape level information about postfire successional pathways among four major community types: shrub communities, herbaceous communities, pure lodgepole pine, and mixed subalpine forests of lodgepole-spruce-fir. We have stratified the burn by topography and vegetation so that these successional patterns can monitored over time, and the permanent field plots will provide important ground reference points in the future that can be linked with future satellite classifications. Eventually, another level could be added to the model to incorporate fire intensity if postfire monitoring reveals that it plays a significant role, and it could be expanded to a landscape level to include various factors such as topographic position.

The Corral-Blackwell Fire is an example of a large, infrequent disturbance that will shape characteristics of the subalpine landscape for hundreds of years. Understanding the immediate postfire dynamics of spruce-fir forests following these rare but significant fire events will help us to better understand the long-term dynamics of this type (Rebertus et al. 1992). Almost all of our current knowledge about the early postfire dynamics in spruce-fir has been inferred from stand reconstruction and chronosequences of older stands rather than working forward from known starting points such as we have attempted. Both approaches are limited by their many assumptions, but the data obtained from each can compliment each other. The Corral-Blackwell Fire provides us with valuable opportunity to investigate many questions regarding postfire succession in spruce-fir forests.

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Figure 1. Projected successional development of lodgepole pine, Engelmann spruce, and subalpine fir from study plots in the Corral-Blackwell Fire. Burned plots are a compositie of high severity and low severity burns within crown fire patches. Projections were developed using the initial seedling densities of each species and FIRESUM.

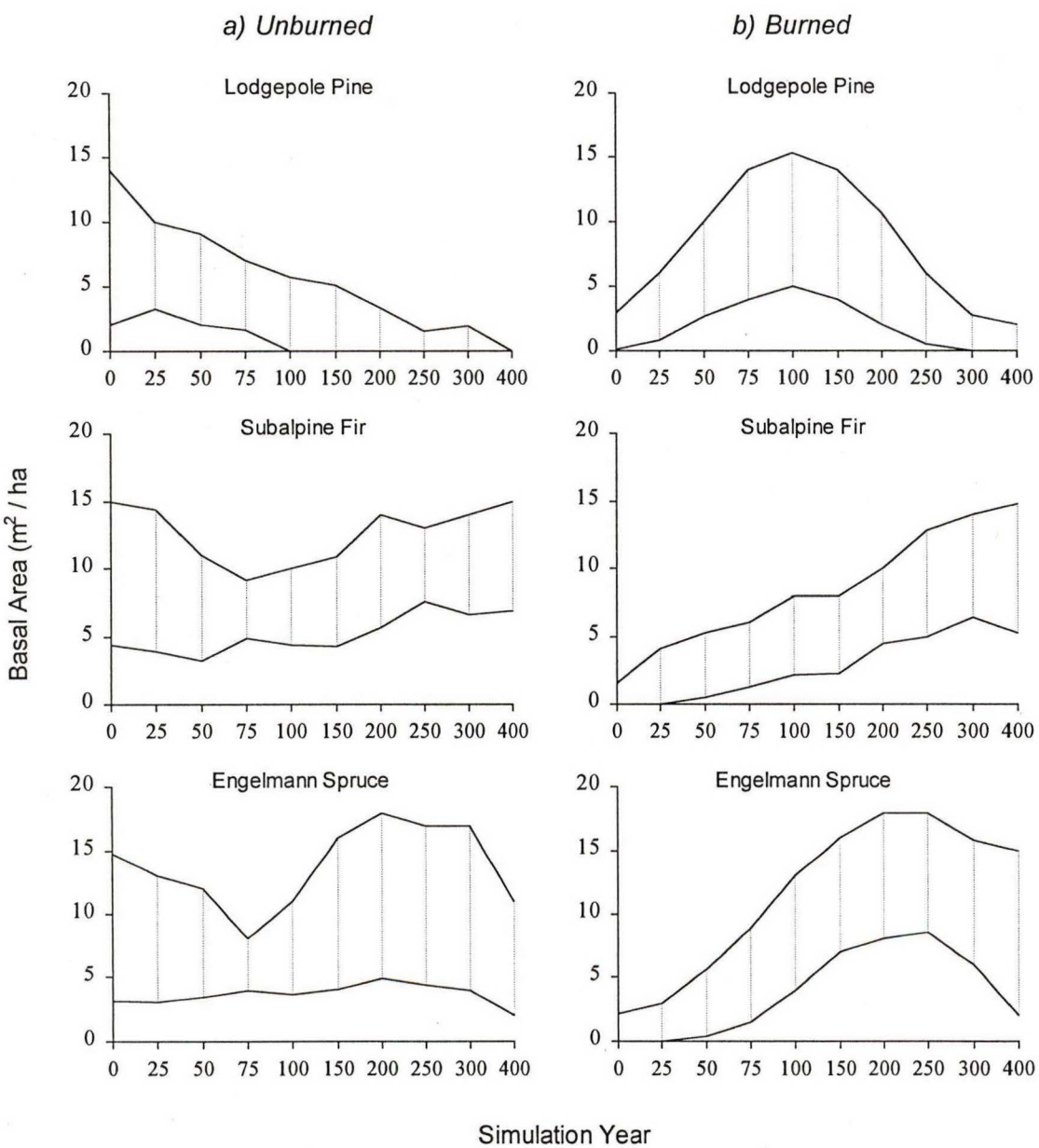


Figure 2. Conceptual model of postfire successional pathways in mixed subalpine forests in central Idaho. Dashed lines indicate a an initial postfire pathway immediately after a fire and solid lines represent successional pathways that may occur in the absence of fire

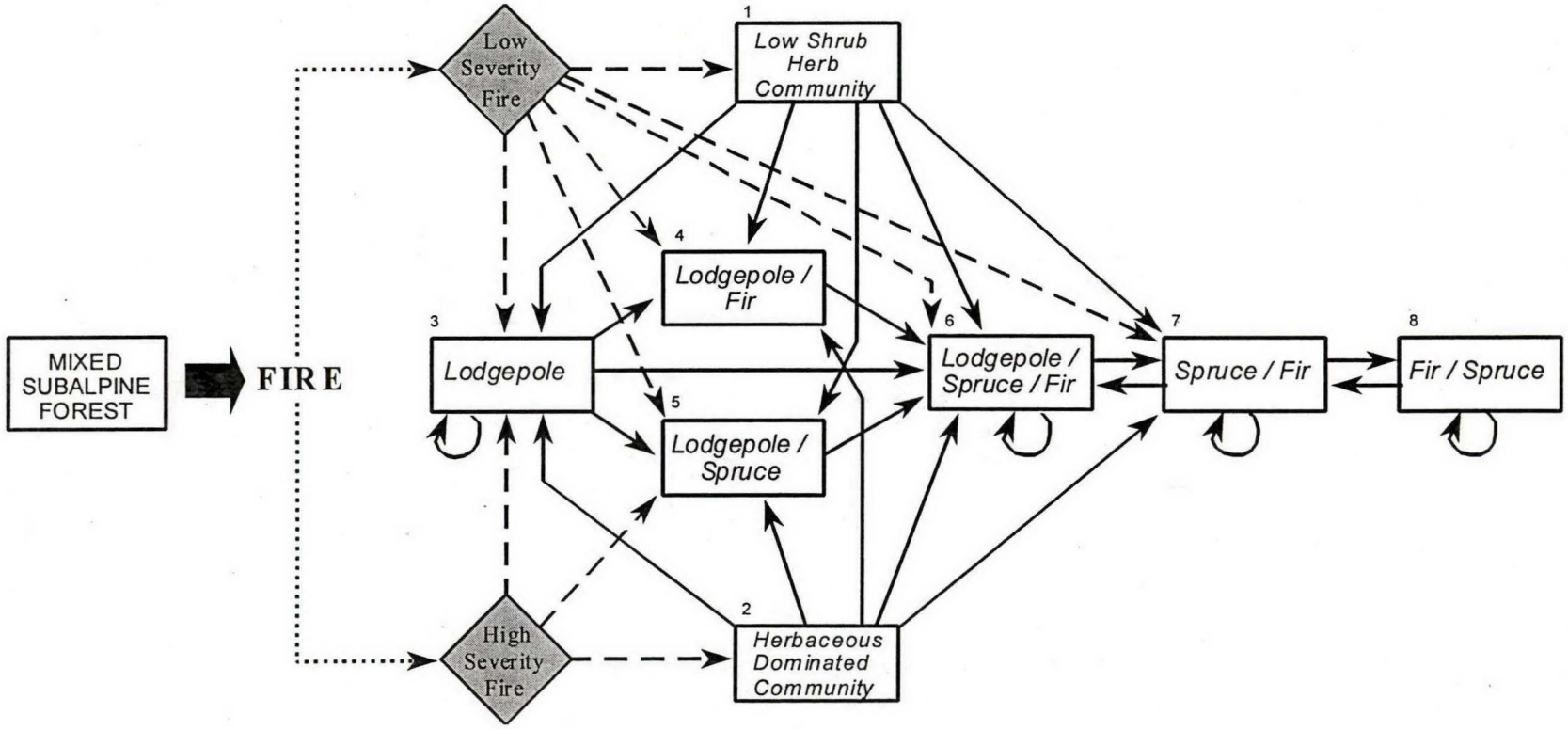
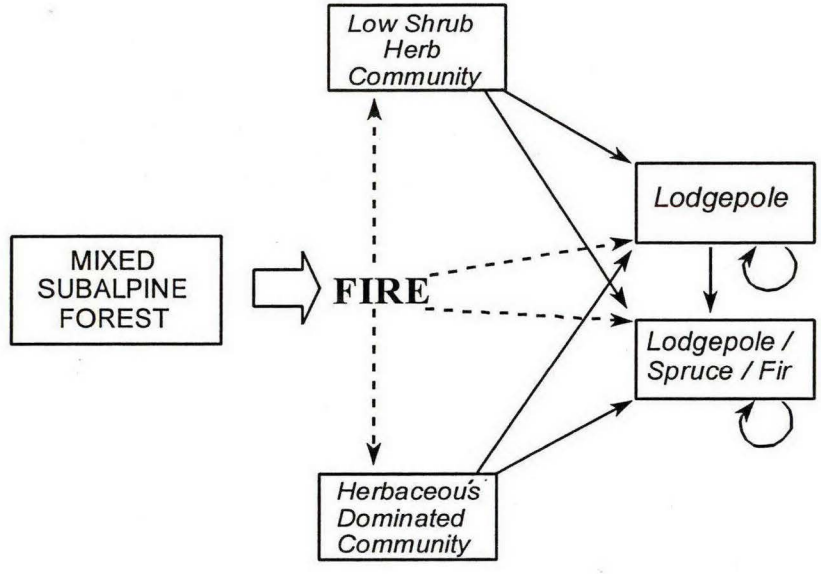


Figure 3. Conceptual model of postfire successional pathways modified for monitoring broad-scale vegetation patterns with Landsat TM satellite Imagery.



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